On the physical nature of the electromagnetic induced transparency effect.

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Abstract

The origin of the electromagnetic induced transparency (EIT) effect is explained not as the vanish of atom-field interaction, but as the growing of stimulated emission process due to the efficient four- photon mixing, which allows the atom to return in the initial state. We point out the importance of creation the new mathematical model for description the dynamics of optical transitions, which should be based on the concept of the time invariance violation in electromagnetic interactions.

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The Bloch equations had been proposed in 1946 for description the nuclear magnetic resonance effect [1]. Now there are the basis for description the dynamics of optical transitions [2]. The mathematical model well describes the physical phenomena, but a great difficulties appear, when anyone wants to understand the physical sense of this descriptions. The rapid adiabatic passage (RAP) effect is the most simple and fundamental example of such phenomena. When the resonance radiation interacts with the two-level system, the so-called periodical Rabi oscillations of the level population take place. In this case the situation is quite symmetrical. But if the sweeping of resonance conditions appears (for example, the frequency of radiation is changed), the full population transfer from the initial level to the opposite one takes place. The theory well describes this effect, but it does not give physical explanation [3]. This is the surprising situation: the mathematical description exists more than fifty years, but any physical explanation of effect is absent till now.

This situation is not an accidental case. It is impossible to explain the origin of RAP effect, if we suppose the equality of forward and reversed transitions. The restriction to equality of integral cross-section of the transitions (equality of the Einstein coefficients) is sufficient for explanation the Rabi oscillations. The physical explanation of RAP effect is possible only if we suppose some inequality between the forward and reversed transitions (in the spectral width, or in the differential cross-section). So, the existence of RAP effect is the indirect proof of such inequality.

Moreover, the number years we have quite direct and complete experimental proof of inequality of forward and reversed transitions. This proof is connected with the existence of the so-called wide component of line in absorption spectrum of polyatomic molecules [4]. This physical object has unusual properties: the large spectral width of optical transition ($\sim 150GHz$) is combined with the long lifetime of the molecule excited states. Its allow to measure separately the parameters of forward and reversed transitions. The measured spectral width of the reversed transition was less than 1 MHz ([5] Fig.5). So, the ratio of spectral width of forward and reversed transitions in this case exceeds five orders of magnitude. Accordingly, the cross-section of reversed transition was found to be orders of magnitude greater, than for the forward one [6]. Such result is a good base for explanation the origin of the effects in nonlinear optics [7].

The goal of this note is to propose the physical explanation of EIT and related effects (self-induced transparency [8], optical pulse compression in a resonant absorber [9], etc.). The usual explanation of EIT effect is based on the conceptions of coherency and interference. There are rather indistinct and vague concepts. It is supposed, that "the effect of EIT is due to the existence of a coherent superposition of quantum states which does not participate in the atom-field interaction ("dark" state) because of a quantum interference of the excitation paths" [10].

In contrast, the present explanation turns our attention on a stimulated emission process. Absorption of energy is a difference between processes of excitation and deexcitation of atoms due to stimulated emission. In terms of ultranarrow width of the reversed optical transition the stimulated emission process may have the difficulty due to the uncontrolled sweeping of resonance conditions (for example, as the result of the ac Stark shift of atom levels in the laser field [11]). Such difficulty can be overcome through the four-photon mixing process, which is strongly facilitated by the presence of powerful resonance radiation on the coupling transition of the lambda-coupling scheme. As the result, the regeneration of the probe laser radiation takes place and the atom returns in the initial state.

The published experimental results sufficiently clearly show both the dynamics of the probe laser field regeneration [12-14] and the existence of the extremely efficient four-photon mixing process in this conditions [10,15-17]. The light "stopping" effect in such experiments does not have, of course, any connection with the speed of photons in the low presure gas mixture. The delay time of the probe laser pulse is the result of the multiple stage of four-photon mixing process and characterizes the build up time of the superfluorescence emission [12].

All processes, which can destroy the four-photon mixing, should lead to growing the absorption of the probe beam. For example, the additional driving field gives the so-called double dark resonance [18]. In this case only six- photon mixing can return atom in the initial state. So, this process is less efficient, than a four-photon mixing. When the probe laser deturn from the resonance in lambda-type coupling scheme, the growing of absorption is observed ([12] Fig.1). In this case we obviously have the variant of the stimulated Raman population transfer [19].

Extremely high efficiency of a four-photon mixing processes in nonlinear optics can be explained as the result of some "memory" of atoms and molecules about the initial state and their aspiration to return back. This "memory" is connected with the inequality of the forward and reversed optical transitions. In other words, this is the result of the time invariance violation in electromagnetic interactions [20]. In spite of common opinion the inequality of forward and reversed transitions is widespread in the optics. There is the base of most phenomena in the nonlinear optics. But it usually manifests itself only in an indirect way, because of the direct and independent measurements of the forward and reversed transitions have some difficulties.

It is important to create the new mathematical model (alternative to the Bloch equations) for adequate description the dynamics of optical transitions. This model should be based on the concept of time invariance violation in electromagnetic interactions [21]. The descriptions of physical phenomena with such mathematical model will have much more straightforward and clear physical sense, than the present day theory descriptions.

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